What Life Scientists Should Know About Molecular Imaging

Nuclear Imaging: Physical Principles and Instrumentation

Hybrid Imaging Systems

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Learning Objectives:

- To become acquainted with a range of hybrid imaging methods, their rationale and principles
- To develop an appreciation of the applications of clinical and preclinical hybrid imaging
- To gain an understanding of technical challenges facing designers of hybrid imaging systems, and recent technological innovations
- To be familiar with potential sources of artifacts in hybrid imaging and how they may be counteracted

Positron emission tomography (PET) and single photon emission computed tomography (SPECT) are nuclear imaging modalities that provide unique spatial and temporal information about biochemical, functional, and molecular processes *in vivo*. Both are used extensively to evaluate diseases in humans, and as research tools in studies with experimental animals. Nuclear imaging techniques are however poor at providing anatomical information. Before the advent of hybrid imaging techniques, anatomical information to aid the interpretation of PET and SPECT images was provided by viewing them side-by side with CT or MRI images obtained in another department. Spatial correlation was limited by differences in scanner geometry and displacement of mobile structures between scans, as well as the ability of the viewer to perceive3D relationships.

Hybrid imaging systems largely overcome the problem of spatial correlation by combining two different imaging technologies, e.g. PET/CT. PET/MRI, SPECT/CT, SPECT/MRI, and PET/Optical, in a single imaging system. The imaging procedure on a hybrid system yields images with complementary information that are spatially matched. Combining these images provides unique and readily interpreted information not available from either image alone.

The best known example of a hybrid imaging system is PET/CT. Fusion of the functional and anatomical images provided by these modalities provides both accurate anatomical localization of abnormalities seen on the PET image, and low noise transmission data that can be used with minimal preprocessing to correct measured PET emission data for attenuation before reconstruction. Although both images are acquired while the patient remains on the scanning couch, they are not acquired simultaneously and there is a possibility the patient may move between scans. This and other potential sources of artifacts will be discussed, along with recent innovations in PET/CT technology. The unprecedented success of PET/CT led quickly to the introduction of the first SPECT/CT systems. Here the combination with CT has proven to be as valuable as it was for PET.

PET/MR, like PET/CT, provides spatially matched functional/anatomical images. However there are important differences. Replacing CT with MR means that there is no CT-related radiation dose. MRI also offers much better soft tissue contrast than CT. As will be shown, it is feasible to design scanners capable of simultaneous PET/MR imaging, to completely eliminate the possibility of spatial misregistration. In addition to anatomical information, the MR component can provide useful functional information, and details of the chemical composition of selected regions, via fMRI and MR spectroscopy techniques, respectively. On the down side however, the MR image cannot provide information about photon attenuation, preventing its use for attenuation correction directly. Thus accurate attenuation correction in PET/MR remains a topic of current research interest.

Optical imaging uses light to interrogate cellular and molecular function in living tissue.

Contrast is derived through the use of exogenous agents, endogenous molecules with optical signatures, and reporter genes. Its use in combination with PET or SPECT enables imaging of two molecular targets simultaneously. Examples of the use of this and other hybrid imaging techniques in translational research will be presented.